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IRON FOUNDRY CUPOLA RECUPERATIVE EMISSION CONTROL DEMONSTRATION

James F. Turner, III

Flynn and Emrich Company

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Industrial Environmental Research Laboratory

January 1976

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16. ABSTRACT The report gives results of a project intended to demonstrate the use of a dry, solid-media heat exchanger for the production of hot blast air for the cupola as an integral part of the air pollution control system. Economic advantages--in the form of reduction in fuel costs, operating costs, and air pollution control equipment costs--were expected. Data on the operation of the cupola and heat exchanger were to be analyzed with, and used to refine, a computer model. The refined model was then to have been used to extend the results to other operations. The system never became operational because of problems in interfacing the operation of the cupola, heat exchanger, and air pollution control systems. The report outlines system design deficiencies, presents the results of the work completed on the computer model, and describes the test equipment selected.

PRICES SUBJECT TO CHANGE

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Iron and Steel Industry	Test Equipment	Stationary Sources		14B
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IRON FOUNDRY CUPOLA RECUPERATIVE EMISSION CONTROL DEMONSTRATION

by

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EPA Project Officer: Robert C. McCrillis

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Office of Energy, Minerals, and Industry
Research Triangle Park, NC 27711

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Office of Research and Development
Washington, DC 20460

January 1976

ABSTRACT

It has been established that it is technically feasible to use the sensible and/or latent heat from exhaust gases of cupolas. The main drawback to such schemes in this country was that recuperative heat exchangers were not justifiable due to fuel costs. The increase in the cost of coke, however, appears to now make such systems feasible.

This investigation was into the possibility of using a dry, solid-media, heat exchanger for producing hot blast air for the cupola. Economic advantages in the form of reduction in fuel costs, operating costs, and air pollution equipment costs were expected. Data on the operation of the cupola and heat exchanger were to be analyzed with and used to refine a computer model. The refined model was then to be used to extend the results to other size systems.

The system was never made operational due to problems in interfacing the operation of the cupola, heat exchanger and air pollution control systems. This report outlines system design deficiencies and presents the results of the work on the computer model and a description of the test equipment selected.

This report was submitted in partial fulfillment of Contract Number 68-02-0286 by the Flynn and Emrich Co. under the sponsorship of the Environmental Protection Agency.

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The majority of this report was authored by York Research Corporation, Stamford, Connecticut 06906, on a subcontract from Flynn and Emrich Company. Special appreciation is extended to Mr. Frank Govan, President of York Research Corporation and Messers. Bruce Ranck and Dennis Martin for their assistance and cooperation.

Mr. Robert C. McCrillis of the Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711, is the Project Officer.

SECTION I

CONCLUSIONS

The demonstration project was terminated due to unforeseen difficulties encountered while interfacing the cupola, heat exchange and air pollution control systems. The major problem was caused by an underestimation of the exhaust gas volume. As a result ductwork was underdesigned. This caused two difficulties. First, the smaller diameter ductwork resulted in a larger than expected pressure drop allowing a portion of the exhaust gases to escape through the charging door. Second, the undersized duct presented a smaller than designed cross-sectional area to the flow resulting in a high gas velocity. The combustion of the CO content of the gas occurred, therefore, beyond the refractory lined duct and caused damage to the steel ductwork.

A second and related design error occurred in the placement of the cross-over ducting from the cupola to the heat exchanger. The distance was insufficient to allow combustion to occur even if the ductwork were of the proper dimensions.

Lengthy delays were also a cause for terminating the project. These delays were caused by the necessity of replacement of the exhaust fan and damaged ductwork and construction difficulties. These delays, damage, and interfacing problems led to a decision that for the system to work as intended, major revamping would be necessary. Any such revamping would far exceed the budget allotted by Flynn and Emrich and the decision to terminate the project was made on this basis.

SECTION II

INTRODUCTION

Flynn and Emrich Company, a medium-sized grey iron foundry, was faced in early 1970 with a problem confronted by all foundries, namely, the necessity of installing expensive pollution control devices to meet local air pollution regulations. Pollution control for foundries is invariably an expensive proposition due to four inherent properties of foundry effluent; namely, high temperature, grain loading, and high volume and small particle size. These three factors require that a temperature reduction mode be incorporated into the control system and that the control device itself be highly efficient. High efficiency usually limits choice to baghouses, electrostatic precipitation or high pressure drop scrubbers, all of which are expensive in initial, operational and maintenance cost. While recognizing the fact that a pollution control system does not have a return on investment the management of Flynn and Emrich realized that a heat recovery system included in a pollution control system does and thereby helps to reduce the cost of the entire system.

There were a number of advantages to be considered in utilizing a recuperative heat exchanger. First, there are the advantages of hot blast operation which are already well documented. Foremost of these from an economic standpoint is a reduction in coke usage per ton of iron melted. Reduction of the coke usage up to twenty percent is common. Also, with the temperature reduced the actual volume of air to be treated by the air pollution control device is reduced. Since pollution control costs are directly proportional to volume, a reduction in cost can also be affected.

With these possible benefits in mind Flynn and Emrich investigated various heat recovery systems then available. The most promising solution appeared to be a system proposed by Combustion Equipment Associates Inc. (CEA). A description and general design criteria of the CEA system can be found in the EPA report entitled, "Iron Foundry Cupola Recuperative Emission Control Demonstration - Design Manual." (1)* In brief, the system utilized a dry-media heat exchanger. The dry media material was ceramic spheres. The exhaust gases were mixed with infiltrated air from the charging door and then combusted in an afterburner. The gases, whose maximum temperature is limited to 1550°F by water sprays, proceeded to the heat exchanger. A water quench follows and the gases pass through a pair of cyclones and then a baghouse. The

*Numbers in parenthesis refer to the references which are listed in SECTION VII, REFERENCES.

gases then exit to the atmosphere. Table 1 lists pertinent design data.

The heat exchanger itself consists of three basic compartments: a hot flue gas section, where the hot exhaust air from the cupola comes into contact with the heat exchange media, thus cooling the exhaust; a blast air compartment where the ambient air enters, picks up temperature from the heated media and then exits as the hot blast; and a transport compartment where the ceramic spheres having transferred energy to the hot blast air are transported back to the hot flue gas section.

The fine mesh ceramic spheres are transported down through the trays as seen in Figure 1. The trays have specified openings and are used to allow the spheres to collect in a fluidized bed with a controlled retention time. The upward flow of the air not only is used to fluidize the bed but also enables the spheres to drop through the opening in the trays to the trays beneath.

Table 1. OPERATING CONDITIONS

Melt rate - max (tph)	15*
Blast air temperature (deg.F)	920
Metal to coke ratio	7.5
Flow from afterburner (ACFM)	63,500
Temperature (deg.F)	2,000
First water quench (deg.F)	1,550
Heat exchanger exit (deg. F)	860
Second water quench (deg. F)	540

*A list of factors for conversion from non-metric to metric units is provided in Appendix C.

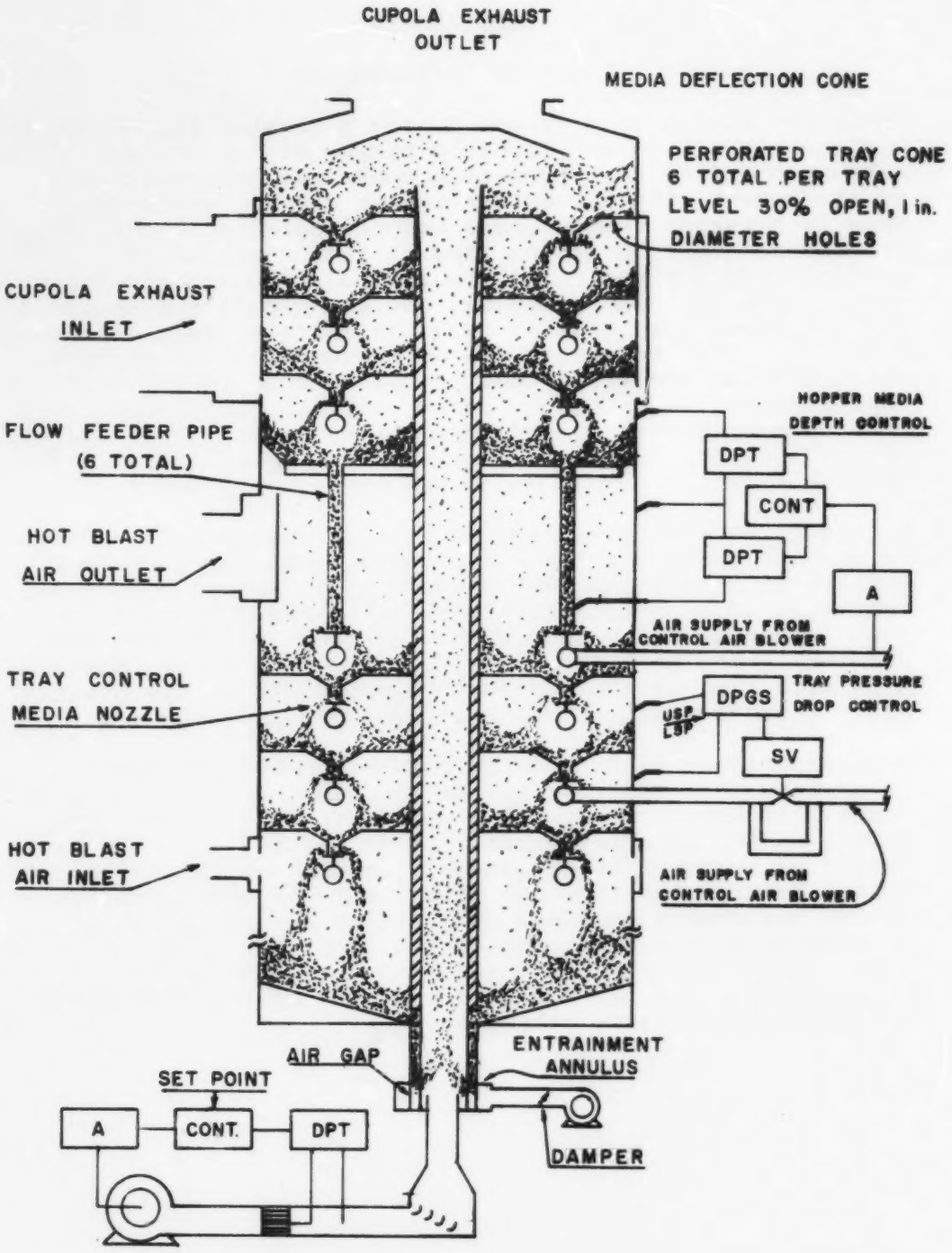

Figure 1. Dry media heat exchanger schematic.

SECTION III

DESIGN DEFICIENCIES

There was basically only one design parameter inaccuracy which was the overall reason for termination of the project. The exhaust gas flow rate from the cupola was underestimated to the extent that the entire system was not operational. This is a rather common error associated with foundry design. The underestimation of the exhaust flow resulted in a corresponding underestimation of the fan requirements and ductwork specifications. Since the fan could not pull the entire flow, exhaust gases were exiting from the charging door to the atmosphere. That air which did go through the ductwork was not combusted completely due to the lack of infiltrated air. This allowed combustion to occur past the refractory lined duct causing damage to the unprotected ducts. Also the lack of infiltration by itself increased the temperature of the exhaust flow above that which had been calculated.

A larger fan was installed but it also was not large enough to prevent gases from escaping through the charging door. Infiltration again was not as much as it should have been, resulting in higher temperatures and delayed combustion. Also, since the flow through the ductwork was higher than originally designed the velocity of the gases was increased. Retention time in the refractorylined ductwork was drastically lessened further aggrevating delayed combustion.

From experience with other foundry air pollution systems it appears that underestimating the flow is the primary design fault. It should always be studied carefully, therefore, before assigning a set value. If at all possible the flow should be measured before installing any air pollution equipment. Knowing the flow and temperature of the exhaust stream allows for a more accurate calculation of the amount of infiltration necessary to reduce the flow to a given temperature. Also, the burnout time of the combustible gases can be determined and the proper dimensions of the associated refractorylined ducts calculated.

SECTION IV

COMPUTER MODEL

One of the main purposes of this test program was to demonstrate the effectiveness of a computer model developed by the Environmental Protection Agency. The purpose of the model was to develop a mass and energy balance on the entire cupola and heat exchanger system. It was anticipated that the model would be verified by the data collected at Flynn and Emrich. The verified model would then have been used to extrapolate the results over a range of system sizes and operating parameters.

At the inception of the contract between Flynn and Emrich and EPA, York Research Corporation was given the job of checking over the model and determining the cost per run. York Research Corporation's system analysts, after reviewing the PACER™ model, determined that there were three problem areas. These areas were:

1. Afterburner modeling
2. Temperature - enthalpy calculations
3. Underestimation of cost per computer run

The computer model of the cupola was originally developed by A.T. Kearney and Company for a different project.[2] Catalytic Incorporated modified the model by changing some of the constants in the reaction equation which were giving incorrect answers.[3] In addition to these changes Catalytic set the READ and WRITE statements in a format that would allow the model to fit in the PACER™ program as developed by Paul Shannon of Dartmouth College.[4] The model of the system was divided into many compublocks as shown in Figure 2. Each block is a subroutine in the PACER™ program system. With a data listing specifying the order of the compublocks and the initial conditions for each block the program would be run to enable a foundry engineer to predict the size of a system best suited to his needs.

The problem with the afterburner modeling was that the compublock used would only calculate mass balances. Since the model was required to balance both mass and energy, this was insufficient. Thus, it was decided to utilize a compublock which would calculate both mass and energy balances. To determine if the integration of this compublock with Catalytic's data list was possible a list involving the proposed compublock was created and studied. This revealed that the proposed substitution would be overloaded by the magnitude of the quantity of combustibles to be reacted. This overloading was solved by reacing each component in the cupola exhaust (i.e. H_2, CO, CH_4) in more than one compublock. The reaction sequence is listed in Table 2.

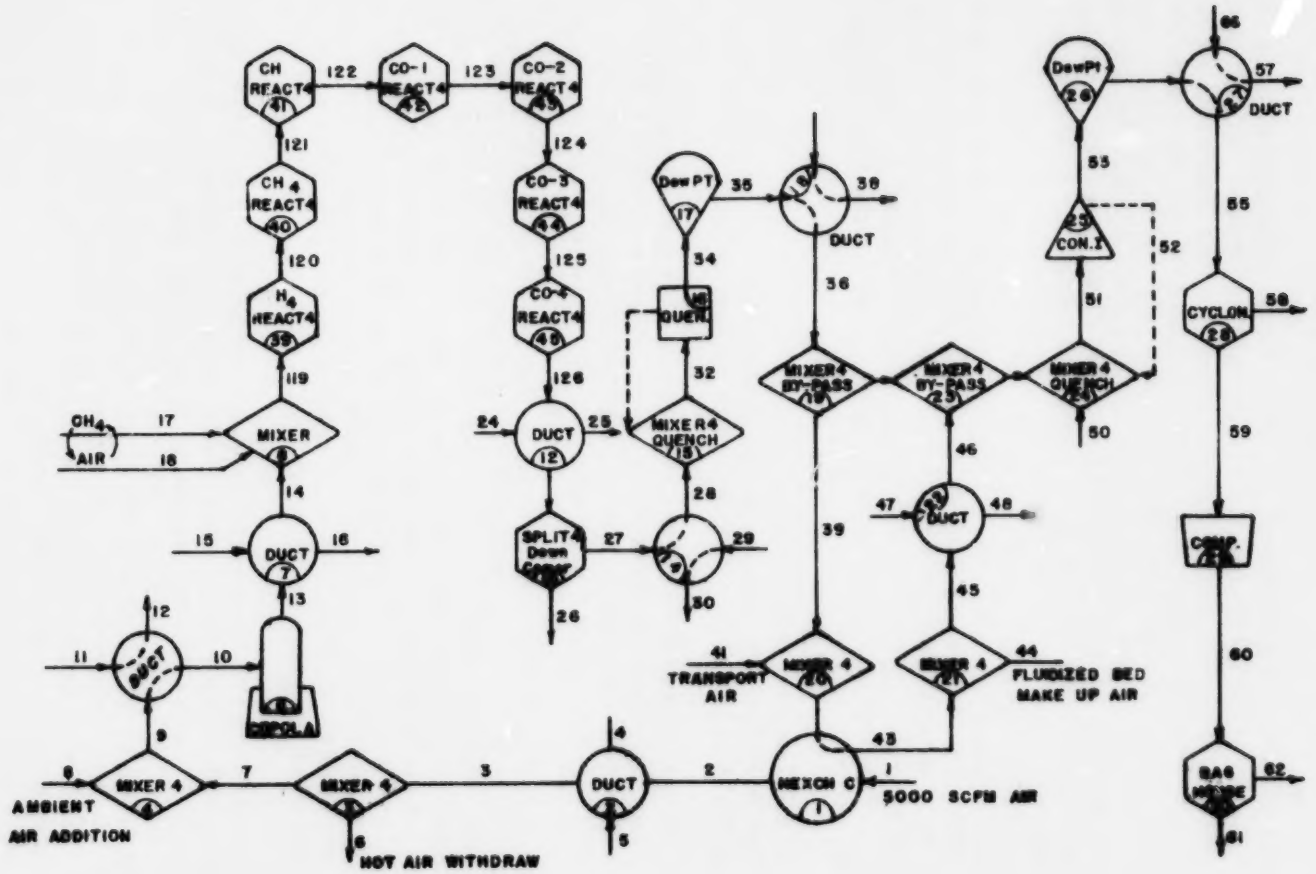

Figure 2. Pacer compublock scheme.

Table 2. AFTERBURNER SEQUENCE

Component	Compublock	% Conversion in Compublock
H_2	H_2	100
CH_4	CH_4-1	50
CH_4	CH_4-2	100
CO	CO-1	25
CO	CO-2	33
CO	CO-3	50
CO	CO-4	100

It was also discovered that the temperature-enthalpy relationships were incorrect for temperatures over 1700°F. Since a large part of the calculation time is spent in the PACER™ data base it is important that the enthalpies are correct.

In correcting the water vapor enthalpies the following procedure was utilized:

1. The water vapor enthalpies in the data base were listed.
2. Data from the Keenan and Kaye "Gas Tables" [5] were fitted to a fourth order polynomial.
3. Liquid enthalpies in the data base were listed.
4. Determined heat of vaporization.
5. The fourth order polynomial was adjusted for the heat of vaporization.
6. Testing of adjusted enthalpy contents.

Figures 2, 3, 4 and 5 show the difference between the original PACER™ data and that generated by the Keenan and Kaye tables. The first constant of the polynomial was adjusted such that an enthalpy difference of 17465.4 BTU/lb mole was obtained between liquid and vapor enthalpies at 212°F. This is demonstrated in Figure 5.

The third problem area involved in the computer model was that of cost. It was evident that the original cost estimate ($5-10) for a complete computer run was substantially below actual cost ($150). It was decided to investigate methods of reducing this cost. This investigation showed that the best way for doing so would involve modelling the fluidized bed heat exchanger more accurately. There are two modelling options for reducing the cost. The first option involves splitting the present compublock into two, allowing flue gas and ceramic balls to be used as two streams. One stream would be used to model the top half and would include the flue gas exchanger and the ceramic balls. The cold blast air and ceramic balls would be included in the other stream which would model the bottom half of the heat exchanger. By reducing the extremes of the inlet temperatures to the heat exchanger compublock in this manner it is reasonable to expect that the temperatures will converge before the 200 iteration limit is reached as is the case with the present method. Exercising this option would mean replacing the three compublocks presently used with seven. Although the use of more compublocks tends to increase the cost, the corresponding decrease in calculation time more than offsets it.

The second option for cost reduction is the same as the above except that a by-pass stream would be added which would model

the amount of air moving between the sections of the heat exchanger. By modeling the components of the heat exchanger individually rather than treating it as a black box, the time required for iterative calculations is decreased.

Evaluation of these options and selection of the better one would have required several computer runs. To economize, it was decided that this could be accomplished simultaneously with the analysis of field data. Since no field data was taken, this evaluation was not undertaken either.

In summary the deficiencies in the computer model have been studied and corrected. The model must still be verified and adjusted by field tests. It is highly recommended that this be done.

A printout of the cupola compublock and PACER™ data list can be found in Section VIII - Appendices.

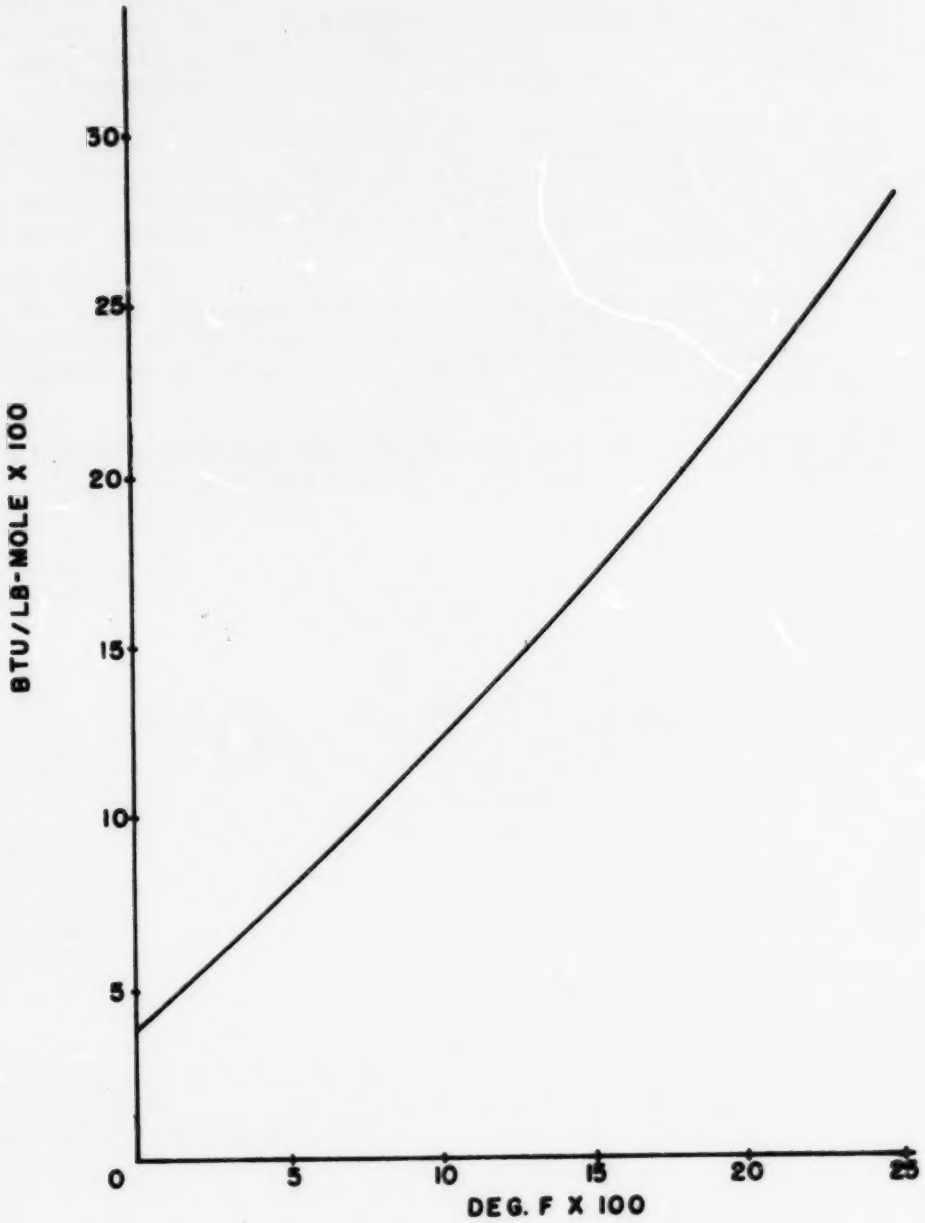

Figure 3. Water vapor enthalpies - Keenan & Kaye data fit at 14.7 P.S.I.

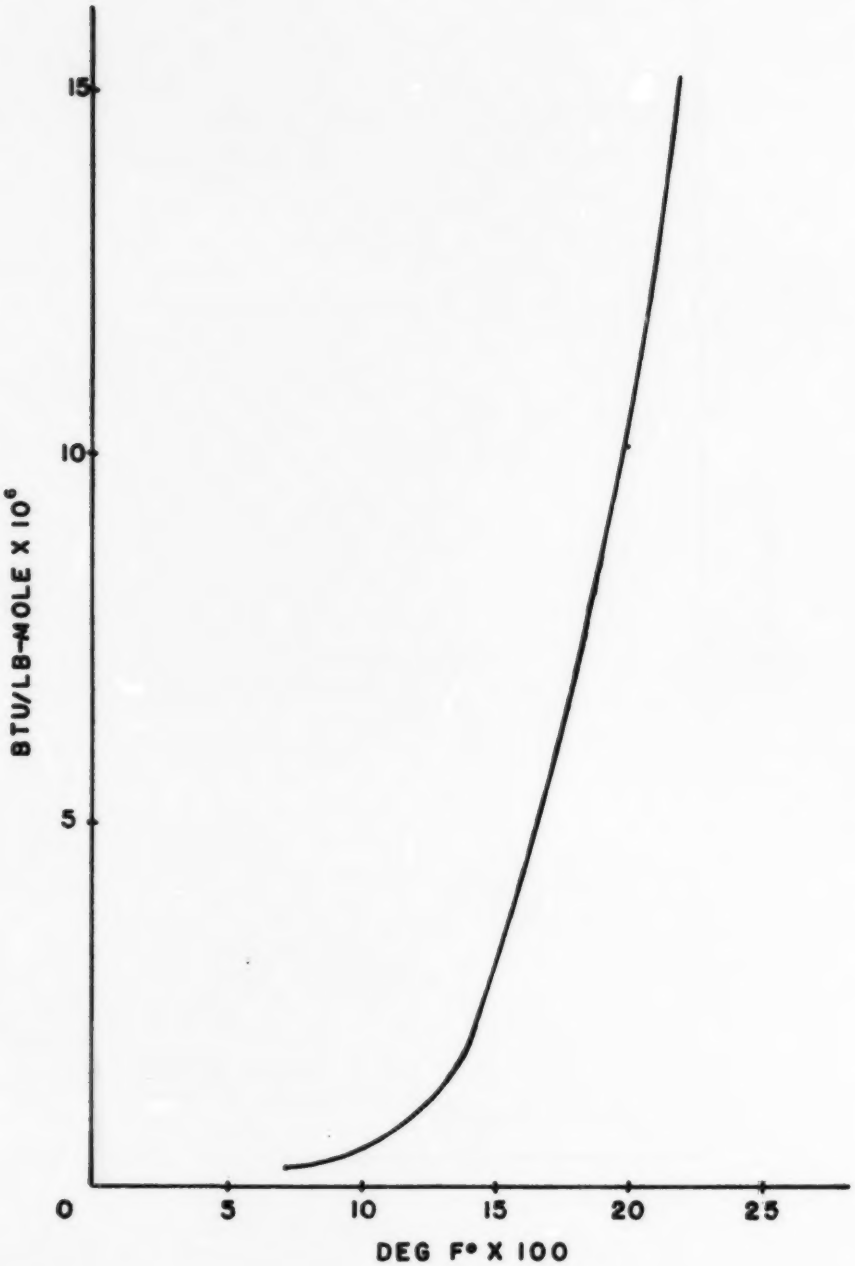

Figure 4. Water vapor enthalpies - Pacer data base at 14.7 P.S.I.

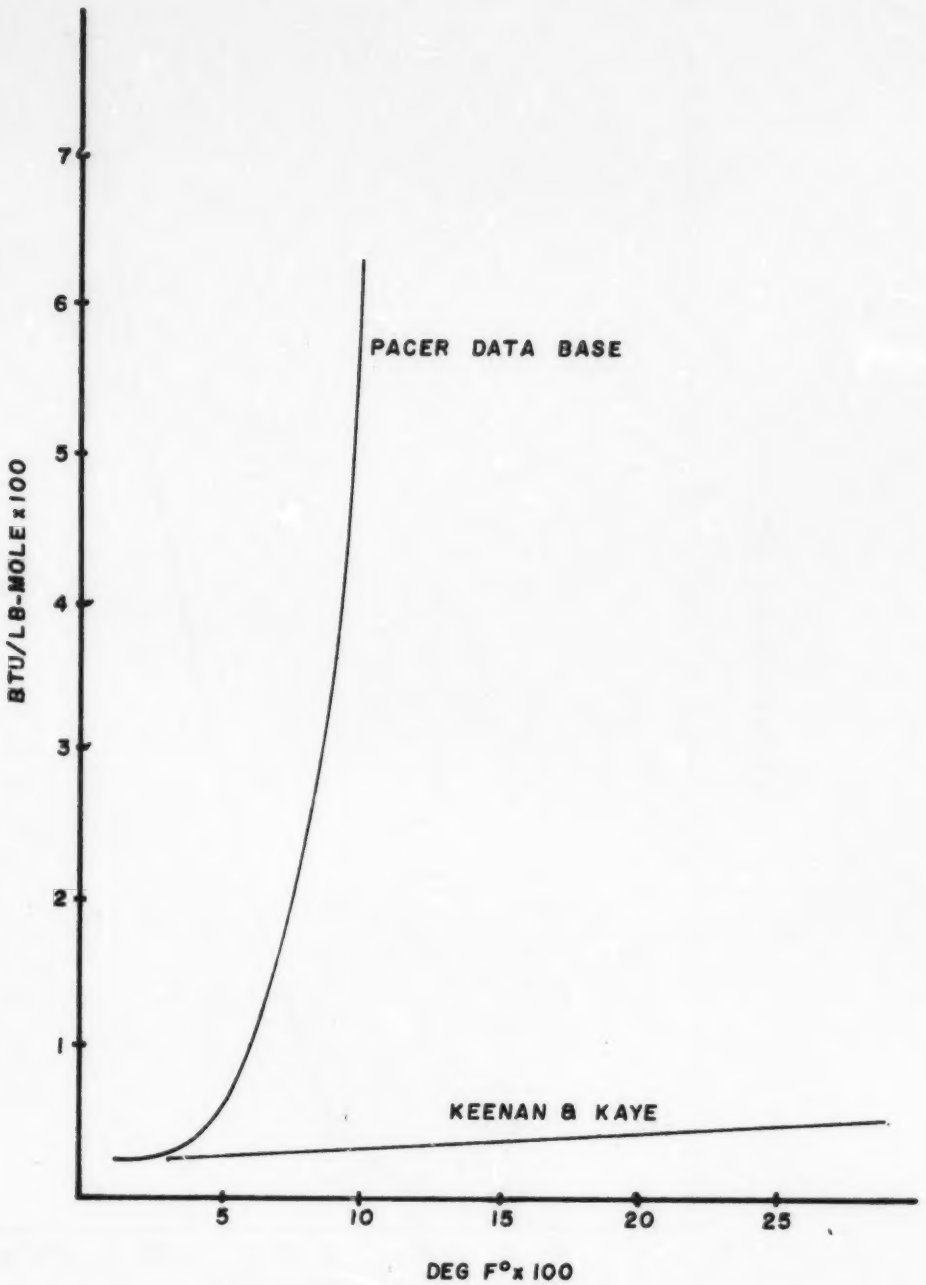

Figure 5. Water vapor enthalpies-Pacer data base and Keenan & Kaye at 14.7 P.S.I.

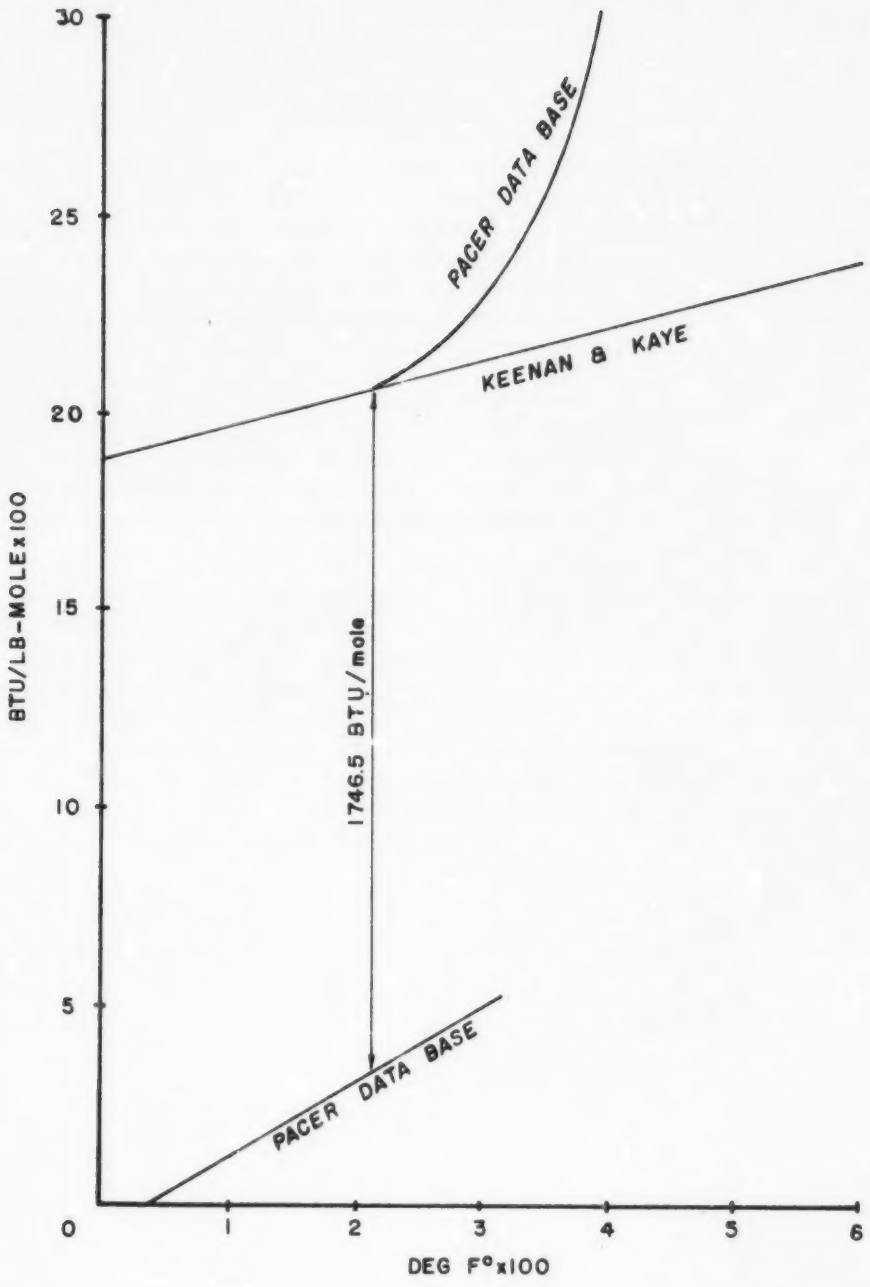

Figure 6. Water vapor enthalpies-Pacer and Keenan & Kaye at 14.7 P.S.I.

SECTION V

MEASUREMENTS

Of vital importance in verifying the computer model is the accuracy of the data. This is especially important since the PACER ™ model is a steady state condition model. Actual cupola operation is, of course, not steady state. It is necessary, therefore, to be able to collect a large amount of data as nearly simultaneously as possible to avoid mixing data from different conditions of cupola operation. In a model study of this type it is necessary to measure numerous properties throughout the entire system and to be able to collect as much data as is possible in a short time period. The equipment that was to be used for this study was picked for its ability to satisfy the above requirements and it is felt that the equipment selection was an important result of the study.

Table 3 lists the various streams that were to be monitored, the physical properties of those streams to be measured and the method of measuring. Table 4 concerns the cost of the equipment purchased and the supplier or manufacturer. That equipment supplied by the Environmental Protection Agency, Flynn and Emrich and York Research Corporation is also noted. Figure 6 shows the positions of the various points to be modelled. Since certain equipment was especially important in this study a brief listing of their specification is provided.

Doric Digitrand Recorder

Description	Model/Option No.	Price
Digitrand Multipoint Data Logger (60 pt)	210-60	$ 3395.00
Group Function Select	01	495.00
Point Ship Pinboard	03	395.00
Remote Control	21	295.00
		$ 4580.00

The first thirty channels were set aside for temperature inputs while the remainder were for recording the electrical signals from the velocity pressure and static pressure transducers. Special equipment to control the pressure readings into the recorder were as follows.

Description	Purpose
Gelman Sequential Valve Assemblies	Sequence pressures to DP Cells.
24 Volt D.C. Power Source	Power step switches and timing circuit.
5 Post Relay Switch	Send pulse to step switches and valves.
Electronic Timing Circuit	To cut 30 second pulse from recorder to three seconds.
30 Second Time Switch	To activate recorder to scan.

Parametrics Aluminum Oxide Hygrometer Model 1000

Description	Part No.	Price
1 Hygrometer	1101	$ 2475.00
4 High Humidity Probes	P2H	1480.00
3 Water Cooled Sample Cells	CS-3	300.00
1 Sample Cell	SC	50.00
4 Matching Calibration	M	350.00
250 Cable	C+250	50.00
4 Cable Connectors		40.00
		$ 4745.00

Cardinal Tip Scale

The self contained full load tip scale comes with the following:

a. 20,000 lb capacity
b. Remote digital printout
c. Recording of weight every two minutes
d. Flip switch for final weight when metal dumps

Cost $10,500

Infrared Thermometer

Description	Part No.	Price
Infrared Thermometer	IT-7A	$ 1575.00
Air Purge Fitting		95.00
		$ 1670.00

Table 3. EQUIPMENT

Material	Physical Properties	Recording Point (S)	Method for Measuring
Inlet air to heat exchanger	Temperature	Temp-1	C/A Thermocouple
	Pressure	Pres-1	Leeds & Northrup DP Cell
	Flow Rate	Flow-1	Fan Evaluator & Hayse DP Cell
	Humidity	Ambient	Weather Service
Outlet blast from heat exchanger	Temperature	Temp-2	C/A Thermocouple
	Pressure	Pres-2	L & N DP Cell
	Flow Rate	Flow-2	4' Annubar & Hayse DP Cell
Outlet air from blast cyclone	Temperature	Temp-3	C/A Thermocouple
	Pressure	Pres-3	L & N DP Cell
Dust from Cyclone 1	Dust Rate	SCL-1	Bucket & Scale
Make up blast air	Temperature	Temp-4	C/A Thermocouple
	Pressure	Pres-4	L & N DP Cell
	Flow Rate	Flow-3	24" Annubar & Hayse DP Cell
	Humidity	Ambient	Weather Service
Total blast air to cupola	Temperature	Temp-5	
		Temp-6	C/A Thermocouples
	Pressure	Pres-5	L & N DP Cell
	Flow Rate	Flow-4	24" Annubar & Hayse DP Cell
	Humidity	HO-1	Hygrometer
Oxygen Enrichment to Cupola	Temperature	Temp-20	C/A Thermocouple
	Pressure	Pres-14	L & N DP Cell
	Flow Rate	Flow-7	Orifice Plate & Hayse DP Cell
Afterburner inlet air	Temperature	Temp-23	Hot Wire Anemometer
	Flow Rate	Flow-8	Hot Wire Anemometer
	Humidity	Ambient	Weather Service
Afterburner natural gas	Flow Rate	Flow-12	Gas meter
	Composition		
	Heating Value	Comp-6	Gas company

Table 3 (continued). EQUIPMENT

Material	Physical Properties	Recording Point (S)	Method for Measuring
Cooling water to cupola	Temperature	Temp-18, Temp-19	C/A Thermocouples
	Pressure	Pres-15, Pres-16	Pressure Gauge
	Flow Rate	Flow-11	Brooks-Meinecke Water Meter
Flue Gas	Temperature	Temp-7, Temp 8	C/A Thermocouples
	Pressure	Pres-6	L & N DP Cell
	Flow Rate	(Flow-6)-(Flow-5)-(HO-3)	By differences
	Composition	Comp-1	Automatic Gas Analyzers
	Humidity	HO-2	Hygrometer & Cooling Cell
Ball Temperature from bottom of exchanger	Temperature	Temp-13	C/A Thermocouple
Water quench before heat exchanger	Flow Rate	Flow-9	Badger Water Meter
Dust from cyclone	Dust Rate	SCL-2	Barrel & Scale
Outlet flue of spray quench (heat exchanger inlet)	Temperature	Temp-9	C/A Thermocouple
	Pressure	Pres-7	L & N DP Cell
	Flow Rate	(Flow-6)-(Flow-5)-(P-8&P-9)	By Difference
	Humidity	HO-3	Hygrometer & cooling cell
Heat exchanger bypass	Temperature	Temp-10,11	C/A Thermocouple
	Pressure	Pres-8,9	L & N DP Cell
	Flow Rate	(Pres-8)-(Pres-9)	Hayse DP Cell
Exit flue from heat exchanger	Temperature	Temp-15	C/A Thermocouple
	Pressure	Pres-11	L & N DP Cell
	Flow Rate	(Flow-6)-(P-8&P-9)	By difference

Table 3 (continued). EQUIPMENT

Material	Physical Properties	Recording Point (S)	Method for Measuring
Media transport air	Temperature	Temp-12	C/A Thermocouples
	Pressure	Pres-10	L & N DP Cell
	Flow Rate	Flow-5	Fan Evaluator & Hayse DP Cell
Tray Control Air Upper Section	Temperature	Temp-21	C/A Thermocouple
	Pressure	Pres-17	L & N DP Cell
	Flow Rate	Flow-13	6" Annubar & Hayse DP Cell
Tray Control Air Lower Section	Temperature	Temp-22	C/A Thermocouple
	Pressure	Pres-18	L & N DP Cell
	Flow Rate	Flow-14	6" Annubar & Hayse DP Cell
Water quench after heat exchanger	Flow Rate	Flow-10	Badger Water Meter
Air flow before cyclone	Temperature	Temp-16	C/A Thermocouple
	Pressure	Pres-12	L & N DP Cell
	Particulate	Comp-5	York Sampling Train
	Flow Rate	Flow-6	Annubar & Hayse DP Cell
	Humidity	HO-4	Hygrometer & Cooling Cell
Air flow after fan	Temperature	Temp-17	C/A Thermocouple
	Pressure	Pres-13	L & N DP Cell
	Particulate	(Comp-5)-SCL-3	York Sampling Train
Dust from cyclone	Dust Rate	SCL-3	Barrel & Scale
Metal charge	Charge Rate	SCL-4	Cupola load scale
	Composition	Comp-2	Cupola load scale and operator
Outlet metal	Flow Rate	SCL-5	Recording scale
	Temperature	Temp-21	Infrared thermometer
	Compositon	Comp-3	F & E Laboratory
Slag	Flow Rate	Inputs-Outputs	By difference
	Composition	Comp-4	F & E Laboratory
Total Electrical Power	Flow Rate	Wa H-1	Demand Watt Meter

Table 4. EQUIPMENT COSTS

Equipment	Quantity	Company	Part No.	Equipment Cost
Water Pressure Gauge	2	Ashcroft Gauges	1000 2" Gauge Brass 1/4" N.P.T.	$ 10.00
Stepping Switch	1	Automatic Electric Co.	RV-66V PW 156315-GF HC	46.43
Infrared Thermometer	1	Barnes Engineering Co.	IT-7A	1670.00
24 VDC Power Supply	1	Baynton Electronics Corp.	(NJE) QR 36-4	149.00
Relay Switch	1	Baynton Electronics Corp.	(Line Electric) RL15D 5 POT-6V-DC	11.75
Water Meter	1	Brooks Instrument	3310-528	1217.00
Outlet Metal Wt. Scale	1	Cardinal Scale & Mfg.	Self contained full load tip scale	10500.00
Multipoint Recorder	1	Doric Scientific Corp.	60 Channel Digitrend 210	4580.00
Annubar	2	Ellison Instrument	732-B/S-6 inch	160.00
Annubar	1	Ellison Instrument	Installed as control equip.	-
Annubar	1	Ellison Instrument	762-303-SS-46 inch	463.00
Annubar	1	Ellison Instrument	742-316 SS-24 inch	219.00
Annubar	1	Ellison Instrument	762-303 SS-48 inch	463.00
Rotameter	1	Fisher & Porter	10A1135MH	60.00
Mechanical Timer	1	Hayden Co., A.W.	R2700-1 cycle/30 sec-115 VAC 1 stack	15.00

Table 4 (continued). EQUIPMENT COSTS

Equipment	Quantity	Company	Part No.	Equipment Cost
Thermocouples	23	Omega Engineering Inc.	1 ft. AB CAIN-18-G-12	$ 529.00
Thermocouples	2	Omega Engineering Inc.	3 ft. AB CAIN-18-G-12	46.00
Recording Hygrometer	1	Parametrics	1101	4520.00
Demand Watt Meter	1	Public Service Co.	-	600.00
Natural Gas Meter	1	Public Service Co.	Installed as control equipment	-
Thermocouple Wire	1500 ft.	Thermo Electric	1500 EA/G-16K, 500	300.00
Thimble Holders	4	Western Precipitation	D-1021	716.00
Alundum thimbles	4	Western Precipitation	D-1022 Type RA-98	21.48
SO_2 Analyzer	1	EPA	Mobile Trailer	-
CO Analyzer	1	EPA	Mobile Trailer	-
CO_2 Analyzer	1	EPA	Mobile Trailer	-
O_2 Analyzer	1	EPA	Mobile Trailer	-
Sequential Valve Assem.	3	EPA(Gelman)	12 Part Valve Assembly	-
0-2" DP Cell	2	EPA(Hayse)	252	-
0-25" DP Cell	4	EPA(Leeds & Northrup)	1911	-
Particulate Train	1	York Research	Test Equipment	-
Hot Wire Anemometer	1	York Research	Test Equipment	-
Inlet Metal Wt. Scale	1	Flynn & Emrich	Installed as control equipment	-
Calibrated Orifice Plate		Flynn & Emrich	Installed as control equipment	-
Dust Scale	1	Flynn & Emrich	Installed as control equipment	-

Table 4 (continued). EQUIPMENT COSTS

Equipment	Quantity	Company	Part No.	Equipment Cost
Barrels	1	Flynn & Emrich	Installed as control equipment	-
Water Meter	2	-	See Specs. for special equip.	150.00
Copper tubing	38/50 ft. rolls	Lee Dopkin Inc.	See Specs. for special equip.	228.00
Temp., pres., & Flow taps	-	-	See Specs. for special equip.	285.00
Timing Circuit	1	-	See Specs. for special equip.	50.00
		TOTAL		$27009.66

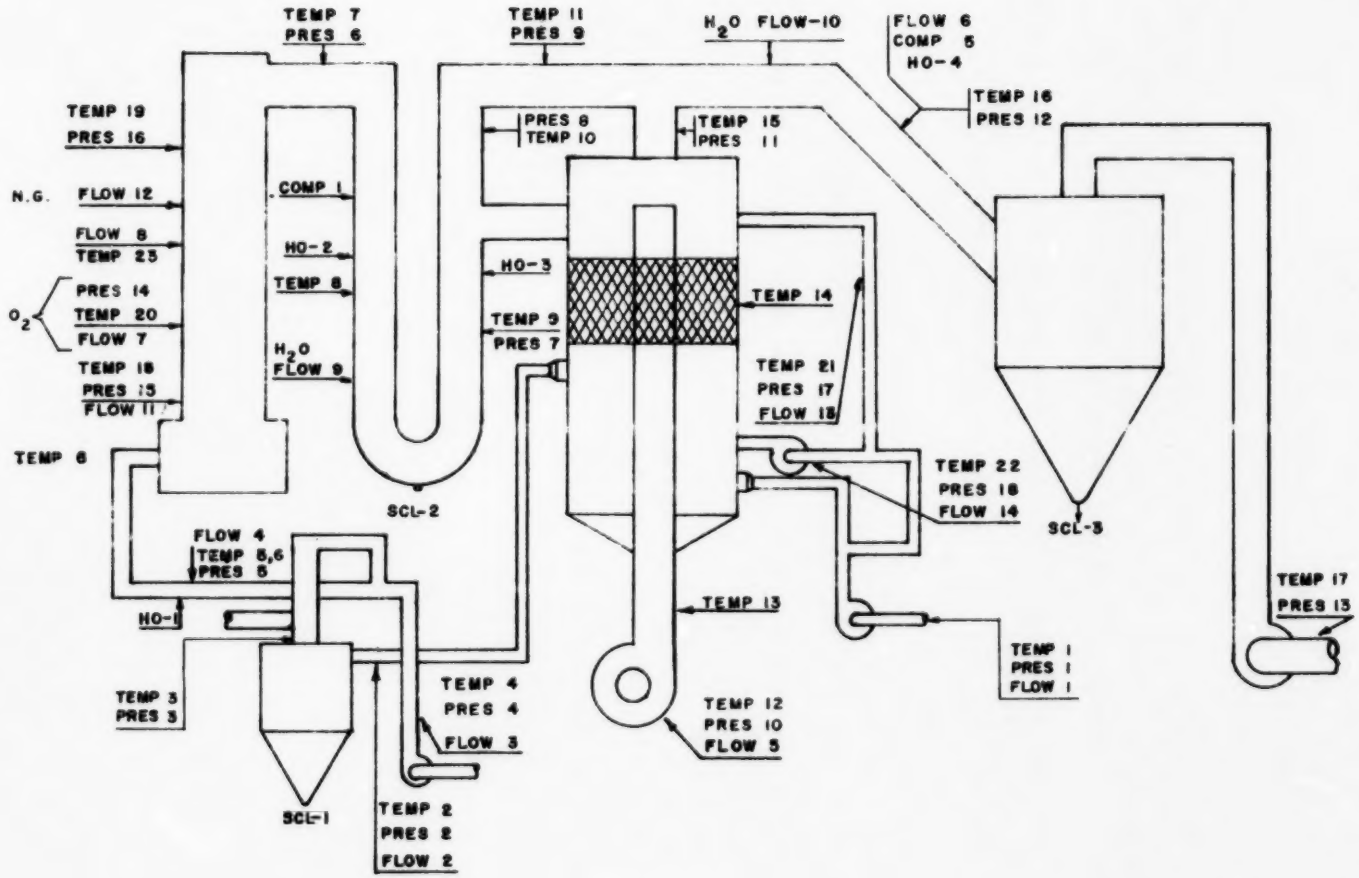

Figure 7. Schematic of test points.

SECTION VI

TEST PROCEDURES

The following test procedure was developed for conducting a test at a given heat and material load on a cupola-heat exchanger system. This procedure would cover a two to three hour set condition which must be held by the cupola.

A. Record initial electric, gas and water meter readings.
B. Tare barrels.
C. Start the following recording equipment:
    1. Gas analyzers
    2. Hygrometer
    3. Scale printout
    4. Multipoint recorder
D. Have cupola operator record metal temperature and time periodically.
E. Have operator record charge composition, weight and time when loading cupola.
F. Conduct particulate test.
G. Measure air flows with hot wire anemometer.
H. Change barrels on the hour.
I. Record water, gas and electric meters on the hour.
J. Record final meter readings, stop recorders, inform operation that the test has ended, weigh barrels.

SECTION VII

REFERENCES

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2. Systems Analysis of Emissions and Emissions Control in the Iron Foundry Industry. A.T. Kearney and Company, Inc. Chicago, Illinois. Contract CPA 22-69-106. Environmental Protection Agency, Research Triangle Park, North Carolina 27711, February, 1971.

3. Catalytic Cupola - Regenerator System Model VIA Pacer. Catalytic, Inc. 1515 Mockingbird Lane, Charlotte, North Carolina 28209. Contract 68-02-0241, Task 12, Final Report (unpublished). Environmental Protection Agency, Research Triangle Park, North Carolina 27711, August 1972, 101 p.

4. PACER™ User Manual, Digital Systems Corp. PO Box 936, Hanover, New Hampshire 03755.

5. Keenan, J.H. and J. Kaye. Gas Tables. New York, John Wiley and Sons, Inc., 1966, p. 108-111.

SECTION VIII

APPENDICES

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A.	Pacer™ Cupola-Compublock Listing	29
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C.	Conversion Factors	44

APPENDIX A

PACER™ COMPUBLOCK LISTING

```
10 TECHNICAL & ECONOMIC FEASIBILITY STUDY OF DRY MEDIA HEAT EXCHANGE SYS
TEM;
20 YORK RESEARCH - ECONOMIC STUDY OF MODEL WITH REACT4>
30 6,5,1010,,1,,200;0,6*1,0,1,0,0,0,0,1,1>
40 DUST,H20,N2,02,CO,C02,H2,S02,CH4>
45 H20/,,-11810.125/,,,,1788.69,-17.053540051,.08273004293,
46 -7.15556145-5,1.2978699-8,-352.35831141,-.046136282091;
50 DUST,1,85/-6710.,24.2/,,,-6710.,24.2/,1,6,9>
60 1,HEXCHC,QEXCHR,1,-2,42,-43;
70 2,HEXCHG,DUCT-1,2,-3,4,-5;
80 3,MIXER4,BLWOFF,3,-6,-7;
90 4,MIXER4,FAN,7,8,-9;
100 5,HEXCHG,DUCT-2,9,-10,11,-12;
110 6,CUPLA4,CUPOLA,10,-13;
120 7,HEXCHG,DUCT-3,13,-14,15,-16;
130 8,MIXER4,ABURNER,14,17,18,-119;
140 39,REACT4,H2,119,-120,
145 40,REACT4,CH4,120,-121;
150 41,REACT4,CH4,121,-122;
155 42,REACT4,CO-1,122,-123;
160 43,REACT4,CO-2,123,-124;
165 44,REACT4,CO-3,124,-125;
167 45,REACT4,CO-4,125,-126;
170 12,HEXCHG,DUCT-4,126,-23,24,-25;
180 13,SPLIT4,CYCLON,23,-26,-27;
190 14,HEXCHG,DUCT-5,27,-28,29,-30;
200 15,MIXER4,QUENCH,28,31,33,-32;
210 16,CONTR1,QUENCH,32,-34,-33;
220 17,DEWPT1,DEWPT,34,-35;
230 18,HEXCHG,DUCT-6,35,-36,37,-38;
240 19,MIXER4,BYPASS,36,-39,-40;
250 20,MIXER4,FAN,39,41,-42;
260 21,MIXER4,FAN,43,44,-45;
270 22,HEXCHG,DUCT-7,45,-46,47,-48;
280 23,MIXER4,BYPASS,40,46,-49;
```

```
290 24,MIXER4,QUENCH,49,50,52,-51;
300 25,CONTRI,QUENCH,51,-53,-52;
310 26,DEWPTI,DEWPT,53,-54;
320 27,HEXCHG,DUCT-8,54,-55,56,-57;
330 28,SPLIT4,CYCLON,55,-58,-59;
340 29,COMPR4,FAN,59,-60;
350 30,SPLIT4,BAGHSE,60,-61,-62>
360 1,1,811,,487.936;
370 2,2,,311.,8.3,24.7;
380 3,.125,.875;
390 4,1.;
400 5,2,,311.,7.82,21.7;
410 7,2,,311.,1.395,50.2;
420 8,1;
425 39,7,1.,,-298.,-57797.9,0,1,0,-.5,0,0,-1;
430 40,9,.5,,-298.,-191759,0,2,0,-2,0,1,0,0,-1;
435 41,9,1.0,,-298.,-191759,0,2,0,-2,0,1,0,0,-1;
440 42,5,.25,,-298.,-67636.1,0,0,0,-.5,-1,1;
445 43,5,.33,,-298.,-67636.1,0,0,0,-.5,-1,1;
450 44,5,.50,,-298.,-67636.1,0,0,0,-.5,-1,1;
455 45,5,1.0,,-298.,-67636.1,0,0,0,-.5,-1,1;
460 12,2,,311.,18.9,10.79;
470 13,,,-1,0,,.057;
480 14,2,,311.,15.27,56.3;
490 15,1;
500 16,1032003,1116.4944,,-.9,,7031006;
510 18,2,,311.,10.15,11.67;
520 19,1,0;
530 20,1;
540 21,1;
550 22,2,,311.,8.8,34.95;
560 23,1;
570 24,1;
580 25,1051003,560.9389,,-.9,,1050006;
590 27,2,,311.,7.05,34.5;
```

```
600 28,,,-1,0,,.672;
610 29,1.01,.7,.6,1.4,1;
620 30,,,-1,0,,1.>
630 1,,,-.23,-.1;
640 2,,,-.05;
650 5,,,-.05;
660 6,,,-1.133;
670 7,,,-.05;
680 12,,,-.02;
690 13,,,-.05;
700 14,,,-.02;
710 18,,,-.01;
720 27,,,-.05;
730 28,,,-.1;
740 30,,,-.15>
750 1,,60.,16.13,,,,138.8,27942,8443.4;
760 4,,60.,14.7,,,,138.8,27942,8443.4;
770 8,,60.,14.7,,,,.01,,01,,.01;
780 11,,60,14.7,,,,138.8,27942,8443.4;
790 15,,60.,14.7,,,,160.,32200,9730;
800 17,,60.,14.7,,,,100.,19350.,5870;
810 18,,60.,14.7,,,8*0,379;
820 24,,60.,14.7,,,,160.,32200,9730;
830 29,,60.,14.7,,,,320.,64400,19460;
840 31,,60.,14.7,,,,2350;
850 37,,60.,14.7,,,,160.,32200,9730;
860 41,,60.,14.7,,,,4.,775,234;
862 42,1,1507.823,14.517,0,0,290.9926,3263.407,44574.26,2368.7406
864 0,14173.211,0,88.605,0;
866 @ STREAM 42 VALUES FROM PAUL'S FINAL REPORT
870 44,,60.,14.7,,,,45.,9700.,2930.;
880 47,,60.,14.7,,,,160.,32200.,9730.;
890 50,,60.,14.7,,,,5247.56;
900 56,,60.,14.7,,,,160.,32200.,9730.;
910 42,,1550.,14.5,,,,290,2900,45000,2400,,14000,,90>>
```

```
920 1,.0001,13*.001>>
930 6,,7500.,42.,25.,1800.,200.,0.,800.,1200.,2*0.,136.,2*0,.993,.03,
940 3*0.,30000.,0,7.5,0..065,.006,.93,0,60.,850.,2800.,3*0,5.3333>
950 1,2,2,2,3,2,4,2,5,2,6,2,7,2,8,2,39,2,40,2,41,2,42,2,43,2,44,2,45,2,1
2,2,
960 13,2,14,2,15,4,16,5,17,2,18,2,19,2,20,3,21,1,22,1,23,1,24,2,
970 25,3,26,1,27,1,28,1,29,1,30,1>
980 CUPLA4,21811>
990 ***EOF
```

APPENDIX B

PACER™ DATA LIST

```
      SUBROUTINE CUPLA4
       INCLUDE KOMMON
C      WATER COOLED CUPOLA MODEL
C      REVISION OF KEARNEY'S BRICK LINED CUPOLA MODEL
C      JULY 1972
C      BY BRAYTON O. PAUL
C      CATALYTIC INC.
C      1515 MOCKINGBIRD LANE
C      P.O. BOX 11402
C      CHARLOTTE, N. C. 28209
C      ********************************************************
       DIMENSION BB1(69),KK1(9)
       EQUIVALENCE (KK1(1),K1),(KK1(2),K2),(KK1(3),K3),(KK1(4),K4),
      *(KK1(5),K5),(KK1(6),K6),(KK1(7),K7),(KK1(8),K8),(KK1(9),K9)
       DATA BB1/
      *.0225,.023,.1,.002,.0195,.012,.024,.5,-.02,-.0155,-.0225,
      *-.0325,-.042,-.025,-.002,-.0325,-.025,-.038,0.,.032,.0325,.0345,
      *.006,.015,.007,.006,.006,.006,.006,.000,-.006,-.006,-.006,
      *.0012,.0005,.0005,.0005,.0012,.0012,.0030,.0000,-.0012,-.0012,
      *-.0003,
      *.45,.06,1.06,.43,
      *.01,.02,.03,.00,
      *.54,.08,.75,.00,
      *.55,.94,.80,.57,
      *1.,2.,3.,4.,5.,6.,7.,8.,9./
       DATA V,Y/2000.,100./
       YY=FETPAR(125)
       CALL STOPAR(125,1.0)
       CALL STOPAR(125,YY)
       DO 606 K10=1,60
       IF (EP(K10+41)) 606,605,606
  605  EP(K10+41)=BB1(K10)
  606  CONTINUE
       K11=0
       DO 630 K10=1,9
```

```
      IF (EP(K10+101)) 630,630,629
  629 K11=K11+1
  630 CONTINUE
      IF (K11) 631,631,633
  631 DO 632 K10=1,9
  632 EP(K10+101)=BB1(K10+60)
      GO TO 635
  633 IF (K11-9) 640,635,635
  640 WRITE (OUT,634) K11,NE
  634 FORMAT(5H ONLYI6,29H OF THE 9 REQUIRED COMPONENTS/
     *49H HAVE BEEN NAMED IN EXTENDED PARAMETERS,EQUIPMENTI6)
 1000 KVOID=1
      GO TO 999
  635 DO 600 K10=1,9
  600 KK1(K10)=EP(K10+101)
      A1=STRMI(1,6)*14.0032
    2 IF (EP(20)) 3,3,9
    3 IF (EP(21)) 4,4,7
    4 IF (EP(22)) 16,16,5
    5 IF (EP(23)) 17,17,6
    6 EP(20)=EP(22)*EP(23)
      EP(21)=A1/33.33333/EP(23)
      GO TO 21
    7 IF (EP(22)) 18,18,8
    8 EP(20)=A1*EP(22)/33.33333/EP(21)*2000.
      GO TO 15
    9 IF (EP(21)) 10,10,14
   10 IF (EP(22)) 11,11,13
   11 IF (EP(23)) 19,19,12
   12 EP(22)=EP(20)/EP(23)
   13 EP(21)=EP(22)*A1/33.33333/EP(20)*2000.
      GO TO 15
   14 EP(22)=33.33333*EP(21)*EP(20)/A1/2000.
   15 EP(23)=EP(20)/EP(22)
      GO TO 21
```

```
 16 WRITE (OUT,716) NE
716 FORMAT(66H EXTENDED PARAMETER 20 (BLAST AIR TO COKE RATIO) MISSING
   *,EQUIPMENTI6)
    GO TO 1000
 17 WRITE (OUT,717) NE
717 FORMAT(53H EXTENDED PARAMETER 22 (TOTAL COKE) MISSING,EQUIPMENTI6)
    GO TO 1000
 18 WRITE (OUT,718) NE
718 FORMAT(62H EXTENDED PARAMETER 21 (METAL TO COKE RATIO) MISSING,EQU
   *IPMENTI6)
    GO TO 1000
 19 WRITE (OUT,719) NE
719 FORMAT(49H EXTENDED PARAMETER 19 (CHARGE) MISSING,EQUIPMENTI6)
    GO TO 1000
 21 IF(EP(27)-1.) 46,46,45
 46 EP(27) = EP(27)*A1
 45 O1 = (EP(27)/14.0032+STRMI(1,K4+6))*2.206*FETVAR(5,K4,2)
    H4 = STRMI(1,K2+6)*2.206*FETVAR(5,K2,2)
    E2 = STRMI(1,K3+6)*2.206*FETVAR(5,K3,2)
    EP(112)=STRMI(1,5)*STRMI(1,6)*2.206*1.8/1000.
    IF(EP(16)+EP(17)+EP(18)+EP(19)-1.01) 49,52,52
 49 DO 601 K10=16,19
601 EP(K10)=EP(K10)*EP(20)
 52 F5=EP(16)+EP(17)+EP(18)+EP(19)
    X= EP(5)+EP(6)+EP(7)+EP(8)+EP(9)+EP(10)+EP(11)+EP(12)
    YY=EP(20)/X
    DO 602 K10=5,12
602 EP(K10)=EP(K10)*YY
    IF ((EP(13) + EP(14) + EP(15))-1.01) 47,54,54
 47 DO 603 K10=13,15
603 EP(K10)=EP(K10)*EP(20)
 54 S9=0.0
    C8=0.0
    U8=0.0
    S2=0.0
```

```
      DO 604 K10=5,15
      S9=S9+EP(K10)*EP(K10+37)
      C8=C8+EP(K10)*EP(K10+48)
      U8=U8+EP(K10)*EP(K10+59)
      S2=S2+EP(K10)*EP(K10+70)
  604 CONTINUE
      IF (S9-(.0040000*EP(20))) 55,55,57
   55 WRITE(OUT,500) S9
   56 S9 = .004*EP(20)
   57 CONTINUE
  500 FORMAT (' S9 = ',F7.2,' S9 SET TO .004 * EP(20)')
      03 = 01 - .86*EP(18) - 1.14*S9 - .41*U8
      V3 = (03 - 10.03*EP(37) - 1450.*EP(38))/(2.66*EP(26))
      H1 = 5.72*EP(37) + 519.*EP(38) + H4
      V4 = .667*H1/EP(26)
      H = .111*H1
      V6 = EP(23) - V3 - V4 - C8/EP(26)
      C1 = 1.55*H1 + 4.66*V6*EP(26)
      IF(EP(35)+EP(36)-1.01)62,62,63
   62 X4 = (EP(20)*4.65/(EP(34)*6.)**1.75)*(EP(35) + EP(36))
      GO TO 64
   63 X4=EP(35)+EP(36)
      EP(35)=EP(35)/X4
      EP(36)=EP(36)/X4
   64 CONTINUE
      C2 = 1.38*03-3.66*V6*EP(26)
      S5 = 2.14*S9+.5*EP(23)*EP(24)+X4*(.6*EP(35)+.2*EP(36))
      U5=.03*EP(24)*EP(23)+X4*.6*EP(36)
      S1 = EP(25)*EP(23) + .0076*EP(37) + 1.34*EP(38)
      EP(32) = (X4+EP(24)*EP(23)+ 2.14*S9 + 1.29*U8)
      DO 607 K10=16,19
      C2=C2+EP(K10)*EP(K10+70)
      S5=S5+EP(K10)*EP(K10+74)
      U5=U5+EP(K10)*EP(K10+78)
      EP(32)=EP(32)+EP(K10)*EP(K10+82)
```

```
607 CONTINUE
    EP(32)=1.02*EP(32)
    S3 = 6.59E-9*EP(32)*(100.*U5/S5)**2.65
    EP(32) = EP(32) + S3
    S4 = 2.*(S1 + S2 - S3)
    R1 = .0156*EP(32)
    EP(31) = EP(20)+C8-S9-U8-R1+S2
    X=2000./EP(31)
    B3 = (A1 + EP(27) + EP(37))/(EP(34)*EP(34)*0.785398)
    D3 = .0625*(B3/32.8 - 3.)
    D4 = 280./EP(22) - 16.
    EP(122)=(E2/28.+C2/44.+C1/28.+H/2.+S4/64.)*.01073*(EP(29)+460.)/14
   *.7
    EP(123)= 520.*EP(122)/(EP(29)+460.)
    D5 = 56. - 29.2/(EP(34)*EP(34)*0.785398*X)
    D6=D3*EP(123)*X
    D7 =(.5*D6+.25*D4+.25*D5)/X
    EP(32) = EP(32) - D7
    A5=0.0
    DO 608 K10=1,NOCOMP
608 A5=A5+STRMI(1,K10+6)*FETVAR(5,K10,2)
    A5=A5*2.206
    06=EP(27)*5.08
    EP(111) = 14.45*((EP(23)- V4)*EP(26) - C8) + 60.*EP(37) + 8470.*EP
   *(38)
    EP(113) = 12.74*EP(18) + 2.05*R1 +13.1*S9 + 3.02*U8
    EP(115) = (EP(30) - 60.)*.4172/X
    EP(117) = 2.16*.75*(.45*EP(16) +.06*EP(17) +.11*EP(18)+.43*EP(19))
    G4=2.54*EP(37)
    G5=446.*EP(38)
    W11=EP(20)+F5+A5+06+EP(23)+G4+G5+X4
    W2=E2+C2+C1+H+S4
    XX=(41.*U5/52.)
    IF(S5-XX) 27,27,28
27  CS=S5
```

```
      GO TO 29
   28 CS=XX
   29 Q6=.82*U5-.44*CS
      EP(118)=2.898*HI
      EP(116)=(EP(30) - 60.)*.321*EP(32)/1000.-Q6
      TOTFLO=0.0
      PHASE=1.0
      PRESS=STRMI(1,4)+EPC(4)
      HPERM=0.0
      TEMP=(EP(29)+459.69)/1.8
      DO 611 K10=1,NOCOMP
  611 COMP(K10)=STRMI(1,K10+6)
      COMP(K1)=D7/(FETVAR(5,K1,2)*2.206)
      COMP(K2)=0.0
      COMP(K4)=0.0
      COMP(K5)=C1/(FETVAR(5,K5,2)*2.206)
      COMP(K6)=C2/(FETVAR(5,K6,2)*2.206)
      COMP(K7)=H/(FETVAR(5,K7,2)*2.206)
      COMP(K8)=S4/(FETVAR(5,K8,2)*2.206)
      COMP(K9)=0.0
      DO 612 K10=1,NOCOMP
      STRMO(1,K10+6)=COMP(K10)
  612 TOTFLO=TOTFLO+COMP(K10)
      CALL BESTKV
      CALL FLASH
      CALL SHGAS
      CALL SHLIQ
      DO 613 K10=1,NOCOMP
  613 HPERM=HPERM+FDV(K10)*HGAS(K10)+FDL(K10)*HLIQ(K10)
      STRMO(1,2)=PHASE
      STRMO(1,3)=TEMP
      STRMO(1,4)=PRESS
      STRMO(1,5)=HPERM/TOTFLO
      STRMO(1,6)=TOTFLO
      EP(119)=HPERM*2.206*1.8/1000.
```

```
      EP(120) = 4.346*C1
      EP(114) = EP(111) + EP(113) + EP(112)
      DO 614 K10=1,NOCOMP
  614 COMP(K10)=0.0
      COMP(K2)=1.0
      TOTFLO=1.0
      TEMP=(EP(28)+459.69)/1.8
      PRESS=1.
      CALL BESTKV
      CALL FLASH
      CALL SCPL
      CALL SCPG
      A10=FDV(K2)*CPG(K2)+FDL(K2)*CPL(K2)
      EP(124)=EP(2)*EP(3)*EP(4)*A10/18000.
      EP(121) = EP(114) - EP(115) - EP(117) - EP(116) - EP(118) - EP(119
     *) - EP(120) - EP(124)
      R5=EP(9)+EP(10)+EP(11)
      R6=EP(7)+EP(12)
      W6=(W2*X)/100
      Z=EP(114)/100
      IF (EP(33)) 609,609,999
  609 CALL EJECT
      WRITE(OUT,131)
  131 FORMAT (////70('-')//5X' MATERIAL BALANCE'//2X' INPUTS'/33X'LBS' 7
     *X'LBS PER TON'6X'PERCENT'/31X,2('PER HR',9X)/)
      YY=EP(20)*X
      ZZ=EP(20)*Y/W11
      WRITE(OUT,132)EP(20),YY,ZZ
  132 FORMAT(13H METAL CHARGE10X,2(F15.0),F15.2)
      YY=EP(6)*X
      ZZ=EP(6)*Y/W11
      WRITE(OUT,133)EP(6),YY,ZZ
  133 FORMAT (9H PIG IRON14X,2(F15.0),F15.2)
      YY=R5*X
      ZZ=R5*Y/W11
```

```
      WRITE(OUT,134)R5,YY,ZZ
  134 FORMAT (8H RETURNS15X,2(F15.0),F15.2)
      YY=EP(8)*X
      ZZ=EP(12)*Y/W11
      WRITE(OUT,135)EP(8),YY,ZZ
  135 FORMAT (12H STEEL SCRAP11X,2(F15.0),F15.2)
      YY=EP(5)*X
      ZZ=EP(5)*Y/W11
      WRITE(OUT,136)EP(5),YY,ZZ
  136 FORMAT (11H IRON SCRAP12X,2(F15.0),F15.2)
      YY=R6*X
      ZZ=R6*Y/W11
      WRITE(OUT,137)R6,YY,ZZ
  137 FORMAT (12H FERROALLOYS11X,2(F15.0),F15.2)
      YY=EP(23)*X
      ZZ=EP(23)*Y/W11
      WRITE(OUT,138)EP(23),YY,ZZ
  138 FORMAT (/5H COKE18X,2(F15.0),F15.2)
      YY=G4*X
      ZZ=G4*Y/W11
C     WRITE(OUT,139)G4,YY,ZZ
  139 FORMAT (12H NATURAL GAS11X,2(F15.0),F15.2)
      YY=G5*X
      ZZ=G5*Y/W11
C     WRITE(OUT,140)G5,YY,ZZ
  140 FORMAT (9H FUEL OIL14X,2(F15.0),F15.2)
      YY=F5*X
      ZZ=F5*Y/W11
      WRITE(OUT,141)F5,YY,ZZ
  141 FORMAT (/19H FLUX AND ADDITIVES4X,2(F15.0),F15.2)
      YY=A5*X
      ZZ=A5*Y/W11
      WRITE(OUT,142)A5,YY,ZZ
  142 FORMAT (/4H AIR19X,2(F15.0),F15.2)
      YY=O6*X
```

```
      ZZ=O6*Y/W11
      WRITE(OUT,143)O6,YY,ZZ
  143 FORMAT (7H OXYGEN16X,2(F15.0),F15.2)
      YY=X4*X
      ZZ=X4*Y/W11
C     WRITE(OUT,144)X4,YY,ZZ
  144 FORMAT (/14H CUPOLA LINING9X,2(F15.0),F15.2)
      YY=W11*X
      WRITE(OUT,145)W11,YY,Y
  145 FORMAT (/17H TOTAL INPUT MTLS6X,2(F15.0),F15.2)
      YY=V
      ZZ=Y*EP(31)/W11
      WRITE(OUT,146)EP(31),YY,ZZ
  146 FORMAT (//2X8H OUTPUTS//12H MOLTEN IRON11X,2(F15.0),F15.2 )
      YY=EP(32)*X
      ZZ=EP(32)*Y/W11
      WRITE(OUT,147) EP(32),YY,ZZ
  147 FORMAT (/5H SLAG18X,2(F15.0),F15.2)
      YY= D7*X
      ZZ= D7*Y/W11
      WRITE(OUT,148) D7,YY,ZZ
  148 FORMAT(/15H EMISSIONS DUST8X,2(F15.0),F15.2)
      YY=W2*X
      ZZ= W2*Y/W11
      WRITE(OUT,149) W2,YY,ZZ
  149 FORMAT (/10H TOP GASES13X,2(F15.0),F15.2)
      YY= E2*X
      ZZ= E2*Y/W2
      WRITE(OUT,150) E2,YY,ZZ
  150 FORMAT (9H NITROGEN14X,2(F15.0),F15.2)
      YY= C2*X
      ZZ= C2*Y/W2
      WRITE(OUT,151) C2,YY,ZZ
  151 FORMAT(15H CARBON DIOXIDE8X,2(F15.0),F15.2)
      YY=C1*X
        =
```

```
      ZZ=C1*Y/W2
      WRITE(OUT,152) C1,YY,ZZ
  152 FORMAT (16H CARBON MONOXIDE7X,2(F15.0),F15.2)
      YY= H*X
      ZZ= H*Y/W2
      WRITE(OUT,153) H,YY,ZZ
  153 FORMAT (9H HYDROGEN14X,2(F15.0),F15.2)
      YY= S4*X
      ZZ= S4*Y/W2
      WRITE(OUT,154) S4,YY,ZZ
  154 FORMAT (15H SU><5:GOXIDE8X,2(F15.0),F15.2)
      WRITE(OUT,265)
  265 FORMAT(//70('-')///5X12HHEAT BALANCE//2X11H INPUT HEAT 13X,'B.T.U.
     *S.',9X,'PERCENT')
      WRITE(OUT,270)
  270 FORMAT (26X9H(000/HR.))
      ZZ= EP(111)/Z
      WRITE(OUT,280) EP(111),ZZ
  280 FORMAT (/15H POTENTIAL HEAT/10H   OF FUEL10X,F15.0,F15.2)
      ZZ= EP(112)/Z
      WRITE(OUT,290) EP(112),ZZ
  290 FORMAT(/14H SENSIBLE HEAT/ 15H   OF THE BLAST5X,F15.0,F15.2)
      ZZ= EP(113)/Z
      WRITE(OUT,300) EP(113),ZZ
  300 FORMAT (/20H HEAT FROM OXIDATION/16H   OF MN, FE, SI4X, F15.0,F15.
     *2)
      WRITE(OUT,310) EP(114), Y
  310 FORMAT (/19H   TOTAL INPUT HEAT1X,F15.0,F15.2)
      WRITE(OUT,320)
  320 FORMAT (//2X12H OUTPUT HEAT)
      ZZ= EP(115)/Z
      WRITE(OUT,330) EP(115),ZZ
  330 FORMAT (/20H HEATING AND MELTING/10H   OF IRON10X,F15.0, F15.2)
      ZZ= EP(116)/Z
      WRITE(OUT,340) EP(116),ZZ
```

```
340 FORMAT (/13H HEAT CONTENT/14H   OF THE SLAG6X,F15.0,F15.2)
    ZZ= EP(117)/Z
    WRITE(OUT,350) EP(117),ZZ
360 FORMAT (/14H DECOMPOSITION/11H   OF WATER9X,F15.0,F15.2)
    ZZ= EP(118)/Z
    WRITE(OUT,360) EP(118),ZZ
350 FORMAT (/13H CALCINING OF/12H   LIMESTONE8X,F15.0,F15.2)
    ZZ= EP(119)/Z
    WRITE(OUT,370) EP(119),ZZ
370 FORMAT (/10H TOP GASES/16H  -SENSIBLE HEAT4X,F15.0,F15.2)
    ZZ=EP(120)/Z
    WRITE(OUT,380) EP(120),ZZ
380 FORMAT (14H  -LATENT HEAT6X,F15.0,F15.2)
    ZZ=EP(124)/Z
    WRITE(OUT,385) EP(124),ZZ
385 FORMAT(/16H HEAT REMOVAL BY/16H   WATER COOLANT4X,F15.0,F15.2)
    ZZ= EP(121)/Z
    WRITE(OUT,390) EP(121),ZZ
390 FORMAT (/20H HEAT RADIATION FROM/13H   THE CUPOLA7X ,F15.0,F15.2)
    WRITE(OUT,400) EP(122), EP(123)
400 FORMAT (//24H VOLUME OF TOP GAS (MCF)/7H ACTUAL7X, F10.0/9H STANDA
   *RD5X,F10.0///70('-')//)
999  CONTINUE
     RETURN
     END
```

APPENDIX C

CONVERSION FACTORS

Environmental Protection Agency policy is to express all measurements in agency documents in metric units. When implementing this practice will result in undue cost or lack of clarity, conversion factors are provided for the non-metric units used in a report. Generally, this report uses British units of measure. For conversion to the metric system, use the following conversions:

To convert from	To	Multiply by
BTU/lb-F	J/kg-K	4184.
BTU/min	W	17.573
BTU/lb	J/kg	2326
cfm	m^3/sec	.0004719
^oF	^oC	5/9 (^oF-32)
ft	m	.3048
gal.	m^3	.003 x 785
gpm	m^3/sec	.00006309
hp	W	745.7
in.wc	N/m^2	248.84
lb	kg	0.454
lb/ft^3	kg/m^3	16.018
oz/in^2	N/m^2	430.922
psig	N/m^2	6,894.757